Presented at the Seventh Midwinter Convention of the American Institute of Electrical Engineers, at a Joint Session with the American Institute of Mining Engineers, New York, February 20, 1919.

WELDING MILD STEEL

BY H. M. HOBART

ABSTRACT OF PAPER

The probability that welding could, with advantage, be more widely used in ship construction than had heretofore been the case, led to the formation, in 1917, of a Welding Committee, which at first was conducted under the auspices of the Standards Committee of the Institute. The Welding Research Sub-Committee, formed in 1918, was a sub-committee of the Metallurgical and Electrical Sections of the Engineering Division of the National Research Council, and the Welding Committee, (under the chairmanship of Professor C. A. Adams) came under the direction of the Emergency Fleet Corporation. The paper is in large part based on the work done by the Welding Research Sub-Committee up to January of this year.

THIS paper deals principally with investigations undertaken by the Welding Research Sub-committee of the Welding Committee of the Emergency Fleet Corporation. The general object of the investigations has been to extend the use of welding in the construction of merchant ships and, specifically, to provide a definite basis for obtaining the best economy and efficiency in employing welding in place of riveting in the construction of the hulls of such ships.

Composition of Ship-Plate Steel. The chemical composition of the steel employed in such hull construction varies with the thickness of the plates. Through the courtesy of Mr. H. Jasper Cox, of Lloyd's Register of Shipping, the following information may be given concerning the kind of steel plate employed in American Shipyards in 1918 for the hull construction of merchant ships.

Lloyd's requirements do not relate to the chemical composition. They require a tensile strength of 58,000 lb. per square inch (40.75 kg. per sq. mm.) for their lower limit and 72,000 lb. per square inch (50.59 kg. per sq. mm.) for their upper limit. For the information of the Committee, Lloyd's obtained from their surveyors at various works data of the carbon content, which are as follows:

Works		Carbon Content for Plates ¼ in. thick	1 in. thick
A		0.14	0.23
B		0.14	0.25
C		0.19	0.25
D		0.20	0.30
E	Upper Limit	0.30	0.35
	Lower Limit	0.24	0.29
F	Upper Limit	0.25	0.30
	Lower Limit	0.21	0.27
G	Upper Limit	0.25	0.35
	Lower Limit	0.22	0.28

For shapes, Works H employ:

Shapes about ½ in. thick, 0.24 per cent to 0.30 per cent carbon.

Shapes about 1 in. thick, 0.28 per cent to 0.35 per cent carbon.

Small shapes such as:

2½×2¼×¼-in. angles, about 0.15 per cent carbon.

4×4×⅞-in. angles, about 0.20 per cent carbon.

From several tons of half-inch thick (12.7 mm.) plate from the yard of the Chester Shipbuilding Company, which was employed in making many sample welds in an investigation designated the Wirt-Jones Tests, seven analyses were made at the Bureau of Standards. The maximum and minimum percentages of each of the impurities for these seven samples were as follows:

	Maximum per cent.	Minimum per cent.
Carbon	0.25	0.24
Manganese	0.46	0.45
Phosphorus	0.043	0.039
Sulphur	0.031	0.027
Silicon	0.052	0.024

For this material the Bureau of Standards reports:

Yield point, 37,900 lb. per sq. in.

Ultimate tensile strength, 63,600 lb. per sq. in.

Elongation in 2 in., 38.6 per cent.

The following manufacturer's data apply to about ten tons of half-inch ship plate supplied by the Worth Steel Company, of Claymont, Del., and to be used for testing electrodes:

Chemical Analysis (Ladle Analysis)

Carbon	0.29 per cent.
Manganese	0.37 per cent.
Phosphorus	0.015 per cent.
Sulphur	0.032 per cent.

Physical Properties

Tensile strength—lb. per sq. inch	67,400
Elongation, per cent in 8 inches	25.25 per cent.

PLATE XXVI.
A. I. E. E.
VOL. XXXVIII, NO. 4

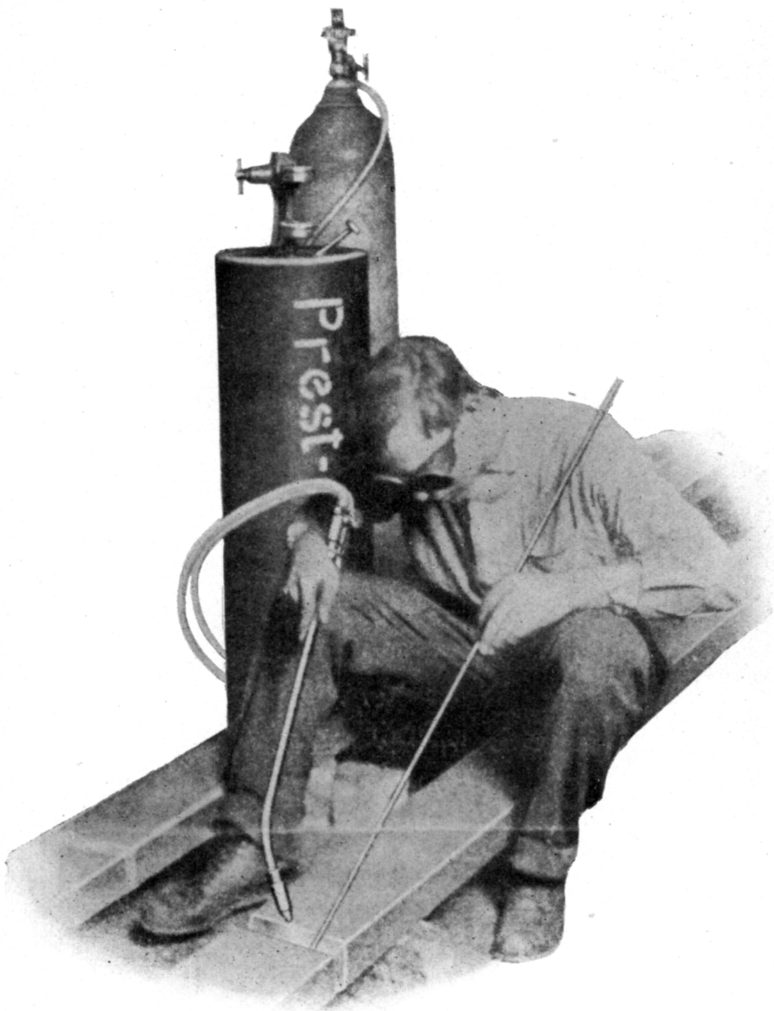

FIG. 1—GAS WELDING [HOBART]

PLATE XXVII.
A. I. E. E.
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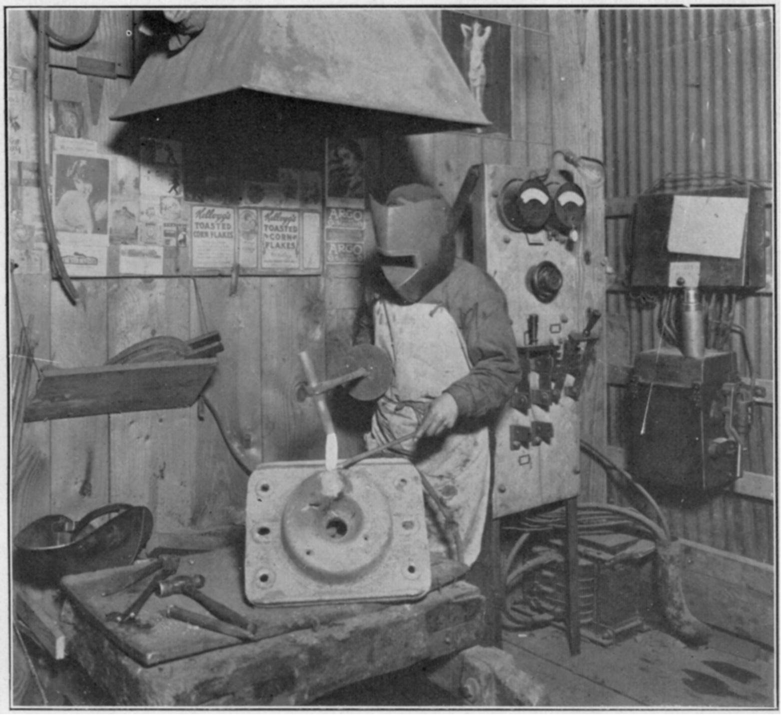


FIG. 2—CARBON-ARC WELDING

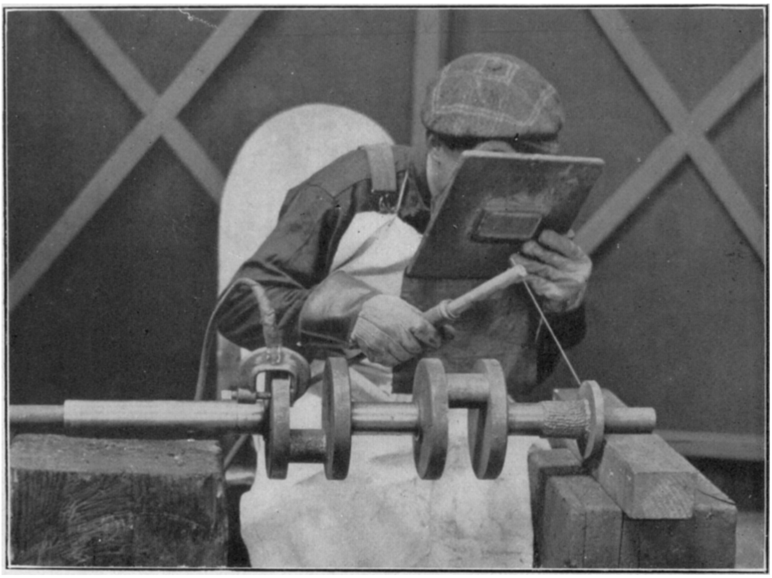


FIG. 3—METAL-ARC WELDING

[HOBART]

Another lot of about 1½ tons of ½-in. and 1-in. ship plate from another source was analyzed by the Electrical Testing Laboratories with the following result, four analyses being made for each thickness:

	Maximum per cent		Minimum per cent	
	½ in.	1 in.	½ in.	1 in.
Carbon	0.24	0.28	0.22	0.26
Manganese	0.44	0.53	0.40	0.47
Phosphorus	0.033	0.033	0.028	0.027

The specifications of the American Society for Testing Materials for structural steel for ships (serial designation A 12–16, p. 98, A. S. T. M. *standard,* 1918) are in abstract as follows:

Phosphorus (acid steel), Not over 0.06 per cent.
Phosphorus (basic steel), Not over 0.04 per cent.
Sulphur, Not over 0.05 per cent.
Tensile strength, between 58,000 and 68,000 lb. per sq. inch.
Elongation, min. per cent in 8 in. 1,500,000/tensile strength.

From the above data we have a good idea of the kind of steel in connection with which it was the Committee's first and specific task to investigate welding.

Two kinds of welding are under investigation at present:

1. Fusion welding.
2. Spot welding.

These are totally different kinds of welding. The fundamental difference is that while in fusion welding no pressure is employed, the success of spot welding is entirely dependent upon the application of both heat and pressure. For the spot welding of thick plates, the required pressure is very great.

The main features of each of these two kinds of welding will now be stated:

Fusion Welding

The term fusion welding is employed to cover gas welding and electric-arc welding.

Gas welding is usually effected by simultaneously fusing with an oxyacetylene flame (1) the material at and near the surfaces which it is desired to join, and (2) some material (which is usually similar in composition) in the form of a rod, the tip of which is subjected to the heat of the flame. The oxy-acetylene flame is directed with one hand and the welding rod is manipulated with the other hand. The operation is illustrated in Fig. 1.

Electric-arc welding may be subdivided into several classes. The two broadest classes are:

a. Carbon-arc welding
b. Metal-arc-welding

In carbon-arc welding, an arc is established between a carbon or graphite electrode (usually a *graphite* electrode) and the two pieces of steel which it is desired to join. This graphite electrode is manipulated with one hand and a welding rod is fed into the weld by the other hand. The operation of carbon-arc welding is illustrated in Fig. 2. The manual activities in carbon-arc welding are seen to be quite similar to those in gas welding. In neither case is it necessary for the material of the welding rod to traverse the arc.[1]

In metal-arc welding, we find a fundamental difference in this latter respect, since in Metal-arc welding of mild steel, the arc, instead of having a graphite electrode for one terminal of the circuit, is established between a steel welding rod (or welding electrode) and the two steel parts requiring to be joined. The operator in Fig. 3 is employing metal-arc welding to build up an incorrectly machined crank-shaft journal. There is always a distance of a matter of a tenth of an inch (2.5 mm.) or more between the end of the welding rod and the work. This distance is bridged by an electric arc. The form in which the steel exists during its passage from one end of the arc to the other is at present the subject of investigation by several independent experimenters.

Their conclusions are awaited with interest. The material cannot pass as a continuous liquid stream, since then there could be no interruptions in the metallic circuit and hence there could be no arc. It can pass as a series of liquid drops, and these can even momentarily short-circuit the arc, the duration of the short-circuit being too brief to be apparent to the operator or ordinary observer unaided by special apparatus. Or the drops can be so minute as to be incapable of effecting

1. Both for carbon-arc welding and gas welding, the edges of the parts to be joined sometimes may be so designed as to obviate the need for any additional material; in other words, no welding rod is necessary in such cases.

a short-circuit. If this should be the case, we can conceive of the metal passing as a stream of finely-divided liquid. Still another possibility is that the steel may pass as a highly-heated gas and condense on the opposite surfaces. It is suggested by physicists that, in its passage through the arc, the steel may undergo instantaneous transformations of which no human knowledge at present exists.

There would appear to be more of these complex possibilities in metal-arc welding than in gas welding or in carbon-arc welding. Nevertheless, it is precisely metal-arc welding which is at present proving very attractive to engineers. It is too early to return a verdict as to whether this wide-spread tendency toward metal-arc welding is based on sound premises or whether there ultimately may not be a reaction (for certain kinds of work) back to carbon-arc welding. It may be that there has been undue precipitancy in the general stampede which has taken place from carbon-arc welding (which was the first to be developed) to metal-arc welding, which is a later development.

Spot Welding

Spot welding, as developed for use in ship construction, consists in bringing into good contact, by hydraulic or pneumatic pressure, over-lapping portions of the plates or parts requiring to be joined, and in sending through the spot of contact a sufficiently large current to heat the plates or parts at this point to a welding temperature. The weld is effected by the combination of pressure and heat.

Several large spot welders have been built. With one of these (which was an experimental machine), sufficient pressure and current were available to weld together three one-inch thick plates. The usual construction of commercial spot welders for use in shipbuilding is similar in general appearance to so-called bull-riveters. The largest spot welder yet built for actual use in ship fabrication has a six-foot (1.8 m.) gap. This outfit is a large stationary machine to which the steel plates and shapes must be brought. It is planned that bulkheads, frames, floors, and other parts shall be constructed with it and shall then be transported by cranes to their places in the ship. This six-foot-gap machine is designed with capacity to weld two three-quarter-inch-thick plates. It provides a pneumatic pressure of 60,000 lb. and a current of 50,000 amperes and welds simultaneously two spots, each of some $1\frac{1}{2}$ inch diameter, in about 30 seconds. With less current a longer time is required, and vice-versa. This particular spot welder, which is shown in Fig. 4, is known as a Duplex Welder. This name is due to the feature that *two* spots are *simultaneously* welded, the current crossing the plate in one direction between two electrodes, and then back again between two other electrodes.

Two transformers, one located on each side of the plate, are comprised in the outfit. The arrangement is indicated, diagrammatically in Fig. 5, in which:

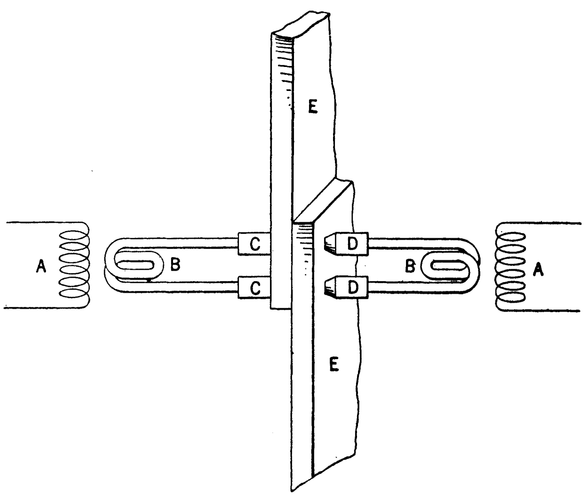


FIG. 5—WIRING DIAGRAM OF DUPLEX SPOT WELDER

A A represents the two primaries.

B B represents the two secondaries (which, in the actual construction, have only one turn each.)

C C and *D D* represent the electrodes between which the current flows and between which the pressure is exerted.

E E represents the two plates to be joined.

The chief object of this duplex feature is to eliminate the large reactance drop of a conducting loop some six feet long and one foot wide when traversed by some 50,000 amperes of 60-cycle current. This amounts to approximately 25 volts. Mr. J. M. Weed, the designer of the machine, reports the interesting fact that the presence in the gap of the plates to be

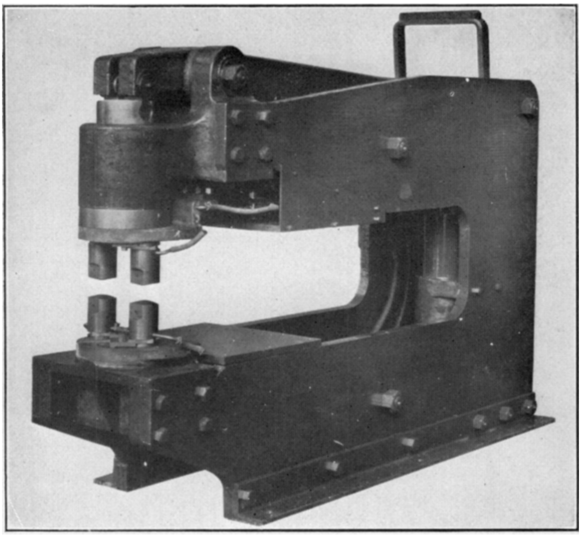
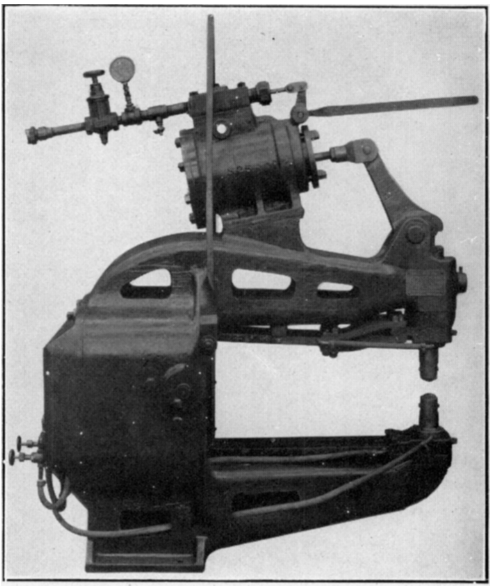


Fig. 4—Duplex Spot Welder



[HOBART]

Fig. 6—Portable Spot Welder with 27-Inch Gap

welded, only decreased the current some ten per cent. This six-foot-gap machine weighs six tons.

In some other large spot welders of somewhat reduced size and capacity, the duplex feature is not employed and only one spot is welded at each application of the current. A portable welder of this type and having a 27-inch (68.5 cm.) gap, is shown in Fig. 6. This machine weighs only 2800 lb. (1271 kg.). In this case only one transformer is employed, and the circuit connections are those shown in Fig. 7, in which:

A represents the primary of the transformer.

B represents its secondary.

C and *D* represent the electrodes.

E and *F* represent the two plates to be welded.

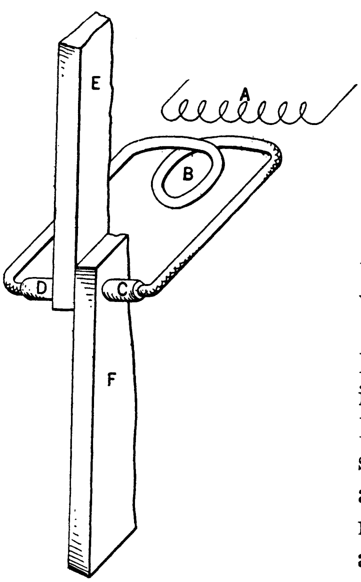


Fig. 7—Wiring Diagram of Portable Spot Welder with 27-inch Gap

In all spot welders for welding thick plates, the electrodes are water-cooled.[2]

When, in the Spring of 1918, Prof. C. A. Adams, of the Welding Committee of the Emergency Fleet Corporation, appointed several of us to be members of a Welding Research Sub-committee, we found ourselves facing a task of great importance and of enormous magnitude. It was desired that our investigations should be directed chiefly to the application of welding in the construction of the hulls of merchant ships. Much interior work on ships was already being performed very successfully with fusion welding and it appeared strongly indicated that the time was ripe for the extension of the appli-

2. Excellent discussions of the subject of spot welding and descriptions of several spot welders built for use in ship construction are given in the four following papers in the *General Electric Review*, December, 1918: Research in Spot Welding of Heavy Plates by W. L. Merrill, p. 919; Spot Welding and Some of its Applications to Ship Construction by H. A. Winne, p. 923; An Electrically Welded Freight Car by Jos. A. Osborne, p. 912; Some Recent Developments in Machines for Electric Spot Welding as a Substitute for Riveting by J. M. Weed, p. 928.

cation to the hulls of ships, with the prospect of producing work not only fully equal (and probably superior) to that obtained by riveting, but also distinctly quicker and cheaper. At the time a welded barge was already nearly completed in England. The Welding Research Sub-committee ascertained that several American railways had for some time employed fusion welding extensively in routine repairs of locomotives and that a matter of possibly a couple of thousand arc welders were at that time employed by American Railways. The extensive and successful use of fusion welding for locomotive repairs, in itself constituted strong evidence of the ability of such welds to withstand vibration and shock in addition to their proved excellence with respect to tensile strength.

Any doubts entertained by the Committee related chiefly to the question of which of many ways in which it had been demonstrated that good fusion welding could be done, was the best way. Furthermore, as regards such mild-steel plates as are employed in the construction of merchant ships, it was soon demonstrated that while sound and quite ductile welds could be depended upon for plates of not over one-half-inch thickness, there was less certainty of good results with plates of greater thickness. But at that time there was no general recognition of the most suitable current to be employed for welding. It was rare to find more than 150 amperes used, even for the heaviest work, and as low as 100 to 125 amperes was found to be frequently employed for welding plates of half-inch thickness.

It now has been quite conclusively shown that stronger and more ductile welds of half-inch-thick plates are obtained by using at least 200 amperes. The author believes that fully 300 amperes should be used for butt-welding three-quarter-inch-thick plates and a matter of at least 400 amperes for one-inch-thick plates. These are some twice as great currents as have heretofore usually been employed in arc-welding plates of these thicknesses.

In view of this subsequent experience, it is clear that the disappointing lack of strength and ductility in certain welds of thick plates made nearly a year ago was a practically certain consequence of using such small currents.

It would be easy to yield to the temptation to enter discursively upon comments and opinions regarding the many points on which experienced welding specialists hold widely divergent opinions. All these specialists are producing thoroughly reliable work, but this is not saying that they are all producing nearly as good work as could be produced under the most appropriate conditions for each case. Indeed, the author's observations lead him to the conclusion that while excellent arc welding is being done on a wide scale, there is a margin for improvement over the present average quality, which, so far as it can be expressed by a sort of resultant of such physical characteristics as:

a. Bending and torsion tests
b. Tensile strength
c. Elongation at fracture

may be assessed as amounting to at least 25 per cent.

The author has attempted to make a list of some of the points which are the subject of discussion, and (while usually not going at much length into the questions), to make reference, in some instances, to the views and evidence on each side of a question. It has been the author's thought that such a summarized presentation might constitute the foundation for an instructive discussion.

The list is as follows:

1. Bare and Covered Welding Wire

The kinds of electrodes advocated and actually used in the art range all the way from the cheapest fence wire, costing but a few cents per pound (say at present prices, some 10 cents per lb.) up to carefully treated and covered electrodes, certain types of which cost over five times as much as bare electrodes. Some makes of covered electrodes are, however, obtainable at reasonable cost (such as, at present prices, some 20 cents to 25 cents per lb.). One type of electrode must yield results uniformly superior to those obtained with another type in order to afford economic justification for a five-times greater price.

2. Salvaging Welding Wire

As to bare electrodes it is generally considered that uniformity is very essential. An operator may be getting along very nicely but will suddenly come to bad places in the welding wire. Heretofore it has been considered necessary to reject such wire. The claim is now made by some people that by merely dipping the electrode wire in suitable material, it may be salvaged. Thus in the Welding Committee's Specification for Electrode Wire (given at page 573 of this paper) occurs a note to the effect that "If electrodes to the above specification sputter or flow unevenly, they may be dipped in milk of lime (whitewash) before welding. This dipping may be done in quantity on stock on hand and allowed to dry, or the welder may keep a pot of solution on hand into which the electrode may be dipped immediately before welding." This method of salvaging electrode wire was developed by the General Electric Research Laboratory.

Also, it has been demonstrated by Mr. E. Wanamaker that the application, by dipping, of a kind of coating which he has developed (and the precise composition of which he will doubtless contribute to the discussion of this paper), permits of doing good work with electrodes which would otherwise be useless.

3. Preferable Kind of Covering for Welding Wire

With regard to covered electrodes, while some claim that a thin covering obtained by dipping, accomplishes the desired purpose, others contend that it is desirable to provide a thick covering of appropriate material, which, in turn, is suitably impregnated. Moreover, even for covered electrodes, the usual belief is that the greatest care should be given to the composition and quality of the welding wire to which the covering is applied. In other words, it is not generally held that the use of inferior wire salvaged as indicated under (2), will permit of obtaining the best quality of welds. It is important that the covering shall be so designed as to be consumed at a definite rate as compared with the rate of consumption of the enclosed welding wire. A consequence is that any particular gage of *covered* welding wire must be used within rather close current limits.

For *overhead welding* one firm exploiting covered electrodes supplies a special (and additionally high-priced) grade in which the covering is impregnated with a more viscous material than is used for the electrodes which the firm supplies for other welding operations.

4. Preferable Composition for Bare Welding Wire

There is a great diversity of practise as to the preferred composition of bare electrodes suitable for welding mild steel plates. As instances of extremes it may be said that amongst widely used electrodes, while one type consists of almost pure iron, other types have nearly 0.2 per cent of carbon and 0.5 per cent of manganese, and still other types run very much higher than this in manganese. This is quite aside from the subject of special compositions for welding high-carbon steel and for welding cast iron. It is anticipated that quantitative measurements will indicate superiority in tensile strength for some

TABLE I.

COMPOSITION OF WELDING ELECTRODES FOR METAL-ARC WELDING

Trade designation of electrode	Carbon	Manganese	Phosphorus	Sulphur	Silicon	Remarks
Page Steel & Wire Co. Armco	0.01	0.025	0.005	0.025	0.005	
Wilson Welders & Metals Co. Grade, No. 6	0.15 to 0.23	0.60 to 0.75	less than 0.04	less than 0.04		Also 0.25 per cent copper.
Grade, No. 9	0.30 to 0.40	about 1.00	less than 0.04	less than 0.04		
Grade, No. 8	0.17 to 0.22	0.30 to 0.45	less than 0.04	less than 0.04		
Grade, No. 17	0.10	0.30 to 0.45	0.06	0.06		
Quasi Arc Co.	0.08 to 0.12	0.45 to 0.55	0.00 to 0.06	0.00 to 0.06	0.05 to 0.08	Flux covering of blue asbestos fibre (Croeodilite) enclosing percentage of aluminum or other metal in form of fine wire capable of giving strong reducing action.
Roebling Co.	0.16	0.56	0.032	0.024	0.016	
Toncan wire	0.10	0.16	0.01	0.046	trace	
Electric Arc Cutting & Welding Co.	0.25	0.30	0.05	0.05	0.05	
Siemund Wenzel Co.	0.10 and under	0.30 to 0.50	0.05 and under	0.05 and under	trace	
Norway-iron Wire	0.05	0.02	0.025	0.007	0.08	
Double Arc Co., of England	0.085	0.35	.....	0.054	0.108	Flux covered.
T. Scott Anderson Co., of England	0.057	0.32	.....	0.026	0.014	Flux covered.
E.A.Jones & Co.,of England	0.22	0.25	0.001	0.026	0.024	Nickle-plated and flux covered.
Engineering and Equipment Co., of England	0.12	0.51	.....	0.08	0.016	Flux covered.
Central Steel & Wire Co. Swedox	0.05	0.18	0.04			
The Spencer Wire Co. Basic open-hearth steel electrode	00.06	0.12 to .20	0.013 and under	0.03 and under		

compositions and superiority in ductility for other compositions. Mr. R. E. Wagner has exhibited some very ductile welds made with electrodes containing small percentages of magnesium and of boron sub-oxide.

It is only within the last few months that there have been available any specifications for use in establishing the merits of welding wire. These are now available in the Welding Committee's specification setting forth a "Standard Procedure for Testing Welding Electrodes." This specification, which is given in Appendix A to this paper, was prepared by the Welding Research Sub-committee in collaboration with Prof. H. L. Whittemore representing the Bureau of Standards and with representatives of manufacturers of welding electrodes.

In Table I are given the compositions of various electrodes in current use. Prior to publication, the data in this Table was submitted to the manufacturers concerned, who, in six instances, improved the opportunity to correct the data to conform with their latest practise. The American Steel and Wire Co. has requested the omission from the accompanying Table of any analyses of electrodes which it has furnished for arc welding. This is for the reason that material has been supplied to a large number of users, and varies considerably in analyses in accordance with the ideas of the purchasers. There does not as yet seem to be an agreement as to the most advantageous chemical composition for electrodes, and the company is not prepared either from observations of the results obtained by its customers or from its own experimental work to make a definite recommendation.

The Welding Committee has issued the following Specification for Electrode Wire for Electric Welding. The specification was prepared under the immediate direction of Mr. Herman Lemp.

SPECIFICATION FOR ELECTRODE WIRE FOR METAL-ARC WELDING IN CONNECTION WITH MILD STEEL

Welding Committee Emergency Fleet Corporation

REVISED TO DECEMBER 20, 1918

(Note:—This wire may or may not be covered)

1 *Chemical Composition*

Carbon	Not over 0.18 per cent.
Manganese	" " 0.55 " "
Phosphorus	" " 0.05 " "
Sulphur	" " 0.05 " "
Silicon	" " 0.08 " "

2. *Sizes and Weights*

Diameter, in mils	Diameter, in fraction of an inch	Pounds per 100 ft.	Feet per 100 lb.
125	$^1/_8$	4.16	2400
156	$^5/_{32}$	6.51	1535
188	$^3/_{16}$	9.37	1066

(Allowable tolerance 6 mils plus or minus)

3. *Material.* The material from which the wire is manufactured shall be made by any approved process. Material made by *puddling process not permitted.*

4. *Physical Properties.* Wire to be of uniform homogeneous structure, free from oxides, pipes, seams, etc., as proved by photomicrographs.

5. *Workmanship and Finish.* (*a*) Electric welding wire shall be of the quality and finish known as the "Bright Hard" or "Bright Soft" finish—"Black Annealed" or "Bright Annealed" wire shall not be supplied.

(*b*) The surface shall be free from rust, oil or grease; a slight amount due to lubrication during last drawing is permissible.

6. *Tests.* Electrodes must, before shipment or after delivery, show good commercial weldability when tested by an experienced arc welder. The electrode material shall flow smoothly in relatively small particles through the arc without any detrimental phenomena.

Note: If electrodes to above specifications sputter or flow unevenly, they may be dipped in milk of lime (whitewash) before welding. This dipping may be done in quantity on stock on hand and allowed to dry, or welder may keep a pot of solution on hand into which the electrode is dipped immediately before welding.

7. *Delivery, Packing and Shipping.* Electrodes shall be furnished in straight lengths of either 14 inches or 28 inches, put up in bundles of 50 pounds or 100 pounds as ordered. Each bundle shall be wrapped in heavy paper securely wired and marked on one end showing diameter in mils, trade name and grade of wire.

5. Composition of Metal Deposited in Weld

A few analyses have been made of chemical compositions of the metal deposited in the weld. Results of the analyses of four sets of electrodes before and after the metal was deposited are quoted below from the Westinghouse chapter in Major Caldwell's report, published by the Emergency Fleet Corporation in 1918. To these results are added analyses of Toncan wire as supplied to the author by Mr. R. E. Wagner.

ANALYSES OF ELECTRODE—PER CENT OF IMPURITIES

	Carbon	Manganese	Phosphorus	Sulphur	Silicon
Roebling........	0.16	0.56	0.032	0.024	0.016
Norway.........	0.049	0.021	0.025	0.007	0.08
C. R. S..........	0.11	0.72	0.097	0.123	0.011
H. R. S..........	0.13 to 0.17	0.50	0.012	0.045	0.011
Toncan.........	0.10	0.16	0.010	0.046	trace

ANALYSES OF DEPOSITED METAL—PER CENT OF IMPURITIES

	Carbon	Manganese	Phosphorus	Sulphur	Silicon
Roebling........	0.05	0.18	0.031	0.036	0.011
Norway.........	0.05	0.018	0.020	0.072	0.011
C. R. S..........	0.05	0.11	0.086	0.072	0.011
H. R. S..........	0.14	0.14	0.012	0.039	0.011
Toncan.........	0.042	0.081	0.019	0.026	0.000

It is notable that most of the carbon and manganese is burned out in traversing the arc.

6. Polarity

For carbon-arc welding, the standard practise is to connect the graphite electrode to the negative terminal. Mr. Wagner states as his experience that it is very difficult to weld with the carbon arc when the polarity of the carbon is positive. He states it to be almost impossible to direct the heat to the point desired and the welding qualities of the arc under this condition are very poor. He concludes: "Our experience has taught us that it is next to impossible to weld with a carbon arc unless the work is positive and the electrode negative."

For metal arc welding with bare wire, the electrode is usually connected to the negative terminal, but instances occur of bare welding wire which works best when the opposite polarity is employed. Also for some particular sizes and sorts of welds best results are sometimes obtained by a reversal of the polarity. With electrodes heavily covered with flux, the positive terminal is almost always connected to the electrode. Plenty of more or less plausible reasons for these differences have been offered on various occasions. On careful reflection none of these reasons prove particularly satisfying. Amongst other considerations the fact of the entire practicability of arc welding from an alternating current circuit and of overhead welding have to be taken into account in judging some of these explanations. As yet, we have no satisfactory hypothesis as to what goes on in the welding arc.

7. Direct Current Versus Alternating Current for Arc Welding

While up to rather recently it had usually been contended that arc welding required a direct-current supply, there are now many advocates of alternating current.

Mr. E. H. Jones in the course of the discussion of Major James Caldwell's paper entitled "Notes on Welding Systems" read on Jan. 22, 1918, before the Institution of Engineers and Shipbuilders in Scotland, stated: "He would like to take this opportunity of drawing attention to the undoubted merits of alternating current for arc welding. For some reason which he was unable to fathom, the general impression was that direct current was superior to alternating for arc welding, but as a matter of fact he found that alternating current was far superior to direct current, and he would recommend the use of alternating current on every possible occasion. Apart entirely from the capital outlay needed, which was vastly higher in the case of direct current, the control of the current was much easier to effect. . . . He estimated that the amount of current which would be necessary to feed 20 operators with direct current would suffice to feed 28 with alternating current."

Mr. R. E. Wagner's experience is as follows: "Electric welding may be done with alternating current as well as with direct current. It is a little more difficult to hold the arc, but this simply resolves itself into a matter of practice. Men who have been regularly doing arc welding with direct current, very quickly learn how to handle the alternating current arc."

At present there is no agreement as to the applicability of alternating current to carbon arc welding.

8. Periodicity for Alternating-current Arc Welding

Amongst the advocates of the use of alternating current, there is no agreement with reference to the periodicity. Although it is generally maintained that arc welding is only thoroughly practicable with as high a periodicity as fifty or sixty cycles per second, there is, on the other hand, expression given to the opinion that the use of twenty-five cycles, or less, is equally satisfactory. In October, 1918, Mr. R. E. Wagner reported to the Welding Research Sub-committee, that he had found from his tests that alternating current for arc welding could be used with a frequency as low as 12½ cycles and as high as 500 cycles. Mr. Wagner states that while there is no difficulty at either of these extreme periodicities, the arc is more readily held at 500 cycles than at 12½ cycles.

9. Bare or Covered Electrodes for Alternating-current Arc Welding

While some maintain that arc welding with alternating current is only at its best when flux-covered electrodes are used, it appears to have been conclusively demonstrated by others that excellent results are being obtained under commercial conditions with bare electrodes and an alternating-current supply. A novice can more quickly learn to weld from an alternating-current supply if he employs flux-covered electrodes. But if he can ultimately learn to weld just as rapidly and successfully with bare electrodes, the difficulties in the initial stages of his education should not be regarded as being of much consequence. Mr. Wagner finds that when welding with alternating current, "manipulation may be simplified in many cases by treating the electrode with a thin coating of ordinary lime."

10. Relative Speeds of Alternating-current and Direct-current Arc Welding

Some contend that alternating-current welding is slower. As an instance of a diametrically opposite experience, the following recently received record of test of a certain electrode may be quoted:

"Its operation on 140 amperes, 115 volts alternating current is very good. It also works satisfactorily on 130 amperes, 75 volts direct current, but the metal flows more slowly on direct current than on alternating current."

The record concerning another type of electrode tested on the same occasion, reads as follows:

"This electrode was tried on 5/16 in. plate, 120 amperes, direct current, 75 volts. Its operation is satisfactory. It also works satisfactorily at 140 amperes, alternating current, 115 volts, but its operation on alternating current is not quite as good as on direct current."

Mr. R. E. Wagner, who has had much to do with the development of both kinds of welding, states that "on the average the speed of welding with alternating current and direct current is about the same. We have had cases where alternating current is faster, and vice versa."

11. Comparative Quality of Arc Welds Made With Alternating Current and with Direct Current

It is contended that the greater difficulty of maintaining an alternating-current arc (involving the necessity of acquiring the skill to hold a very short arc,) entails as a consequence that an alternating-current weld is of superior quality. An experienced observer reports his experience as follows:

"Tests made have demonstrated conclusively that it is possible to do as good, or perhaps better, welding with alternating current as with direct current. No very decided difference has been noticed between welds made with alternating current and those made with direct current, but the welder who did most of the alternating-current welding says that in his opinion the alternating-current welds are better than the direct-current welds. This same opinion has been expressed by the machinist who made repairs on a small tank welded with alternating current. He said that the weld metal was better, more dense, and had fewer blowholes than a direct-current weld."

But an opinion from another authority of great experience in arc welding is as follows:

"As regards the strength of an alternating-current weld there is not the slightest doubt that a greater strength can be gotten on a test piece if that is all the work the man is going to do for some time. The facts, however, are that as the man's hand becomes fatigued in holding the alternating-current arc, his consequent breaking of the arc becomes more frequent, which means less strength in the weld, because every time the arc is broken, a bad spot is left in the weld."

12. Consideration of the Power Factor for Alternating-current Arc Welding

A view presented with considerable persistency is that the low power-factor associated with alternating-current welding leads to capital and operating costs offsetting any advantages. One answer made is to the effect that since for ship welding on an extensive scale, motor-generators are required, this only affects the generator and its circuit and does not affect conditions as regards the motor or the circuit from which it is supplied.

13. Consideration of the Circumstance that Alternating-current Arc Welding is Essentially a Single-phase Load

Similar considerations are involved in regard to the necessity of providing for the characteristics of a single-phase load. It is well known that single-phase motors and generators are much heavier, more expensive and less efficient than polyphase motors and generators. With 30 or 40 arc welding outfits distributed fairly evenly on the different phases of a polyphase system, the load would be sufficiently balanced to be satisfactory, but this would correspond to an unusually large welding installation. In most cases it will be necessary to arrange for the welding to constitute a single-phase load and to make adequate provision to obtain satisfactory service with this condition.

Regarding the possibility of improving the power factor, Mr. W. S. Moody makes the following very suggestive statement.[3]

"Where a number of arcs are to be used within a reasonable distance of each other, the series system may be used. In this arrangement the secondary of an ordinary constant-current transformer supplies current to the primary of all the welding transformers in series. The individual transformers insulate the welding apparatus from the series circuit and transform from the series current to current of proper value for the arc. In this case the inherent reactance of the series transformer is low, but other features of the design are the same as those discussed above. The power factor of such a system can be safely made much higher than where individual arcs are operated in multiples from constant potential circuits."

14. Spot Welding is a Single-phase Load

Mr. J. M. Weed, who has had a great deal of experience with large spot welders, has kindly written the following paragraph on this subject:

"For welding plates from 3/8 to 3/4 in. in thickness, the single-phase currents required would be from 30,000 to 50,000 amperes and the kv-a. required at 60 cycles would range between 300 and 900 at power factors of from 0.35 to 0.50. These low

3. *General Electric Review* (December, 1918) p. 937.

power factors, combined with the fact that this load would be for short periods at very frequent intervals would make it decidedly undesirable from the central station standpoint. The condition would be much improved at 25 cycles, as the same machine would operate equally as well at 25 cycles as at 60 cycles, with about half the kv-a. and about double the power factor. The intervals of operation would however, be the same as for 60 cycles. If, however, a motor generator set with suitable flywheel attached, be provided for operating these machines, these disadvantages are all practically eliminated, this arrangement being such that the motor stores up energy in the flywheel during the interval of no load, the flywheel supplying a large part of the energy during the period of welding. By this means, for instance, a single phase load of 900 kv-a. at 0.50 power factor for 30 second periods and with intervals of 1½ minutes between periods would be converted to a practically continuous 3-phase load of approximately 200 kv-a. at about 0.85 power factor."

15. Ductility of Arc Welds

Attention has been pertinaciously drawn to results of a very few tests which have appeared to indicate that metal-arc welds are inherently utterly deficient in ductility, yet the Committee has had also before it the results of many well-authenticated tests of ductile metal-arc welds.

It has been claimed that gas welds are more ductile. On this matter Mr. R. E. Wagner writes:

"At several meetings of the Welding Committee, special stress has been brought to bear on the bending qualities of acetylene and gas welds. We have done some experimenting with average acetylene and arc welders, and our impression is, that the acetylene and arc welds are in the same class with respect to bending. I submit herewith (See Fig. 8) a photograph showing comparative bends in acetylene and arc-welded joints, both welds were taken from half-inch plate and both samples were bent under the same conditions, that is, the sharp edge of an angle iron was placed along the weld and pressure applied to the angle iron to make a sharp bend. These I think are average comparative results. * * * * * * As far as our experiments are concerned, we feel, as regards physical characteristics, that acetylene and arc welds are in the same class."

16. Respective Fields of Gas and Electric Arc Welding

On this subject, under date of Oct. 22, 1918, Mr. R. P. Jackson, reports to the Welding Research Sub-Committee as follows:

"With reference to the comparative uses or fields of gas and electric-arc welding which came up at the last meeting, it was thought it might be well for some of us to express our opinions on the matter based on our experience with both kinds of welding. In general, we have found gas welding to be more satisfactory for thin material, say 1/8 inch and under, and for general repair work, particularly where various kinds of steel and cast iron are involved. For example, if repairs have to be made on broken machinery, lugs rebuilt, pieces attached to high-carbon steel and work of this character, then the gas-welding methods are superior and the extra cost not ordinarily prohibitive. When it comes, however, to depositing a large amount of metal and welding up structural steel or plates of 1/4 inch thickness and upward, the results obtained by the ordinary direct-current arc with the metal electrode are at least equal to the gas welding work and certainly cheaper. In general, too, the finish of gas welding is more regular and better looking and where that is a consideration it may give a preference to gas. In fact, in the Westinghouse factory at East Pittsburgh, there has been considerably more gas work done than electric, but the electric arc welding is on the increase, not so much in displacing gas as in displacing riveting."

A view taken from a gas welding publication is as follows:

"The arc process is chiefly used for filling up blow holes in large steel or iron castings and building up worn surfaces which have not to be machined. With this process the results obtained are somewhat uncertain, and it is generally conceded, apart from the vital question of cost, that fusion produced by the burning of gases is to be preferred to the electric process. Welds made by the electric process are sometimes rough, hard, brittle and unworkable—in most cases this is highly objectionable, but not always so. With any fusion method of welding, annealing of the metal adjacent to the weld is desirable. It is impossible to do this annealing with an electric welder, but with gas welding the blow-pipe flame can be used for heating up the metal surrounding the welded part, and also for heating metal away from the weld, so as to counteract any strains that may be set up in the piece as the weld cools off. There are certain classes of work for which electric welding is the most suitable system, and, on the other hand, there are many classes of work where it would be most impractical, and which can be done satisfactorily only with gas welding. For general workshop use, a gas welding outfit is far better, not only because of its greater economy in installation and operation, but also because of its wider range of usefulness."

In the absence of any experience to the contrary this latter view appears fairly plausible, and it is natural that it should have received wide acceptance. But an enormous volume of experience in arc welding has gradually accumulated and it controverts the correctness of the view. Unfortunately the experimental data available on the subject of *Gas Welding* is surprisingly meagre. The Welding Research Sub-Committee has concluded that there is practically no test data from which it can draw any safe generalizations as to the mechanical characteristics of *gas welds,* and that it will be necessary to embark upon its own investigations to obtain suitable data.

Gas welding was an established art before there was any large amount of electric welding. This was still the state of affairs in England until shortly before the author was there in the autumn of 1917. But the war conditions had occasioned in England such a shortage of supplies of oxygen and carbide that the Government, as a war measure, practically forced the wide substitution of arc welding for gas welding. The British Government, in entering upon this policy, had relatively little concern as to the comparative merits of the two methods except in so far as that any merit or advantages found to be associated with arc welding would naturally assist in bringing about its use in place of gas welding.

It was, however, with considerable surprise that it was ascertained that the true economic field for arc welding as compared with gas welding was a very wide one, and that, simply due to inertia and tradition, engineers had been continuing in the contrary belief. Major James Caldwell, of the Admiralty Controller's Department, had wide responsibilities in this task of substituting arc welding as rapidly and generally as possible. Major Caldwell provided the author with the results of his investigations into the relative cost of gas and metal-arc welding. These results, which correspond to conditions in December, 1917, are set forth in Table II.

From Table II it is seen that metal-arc welding was found

TABLE II.—COMPARATIVE COSTS OF WELDING BY OXYACETYLENE AND METAL-ARC WELDING

Thickness of metal, inches	Oxyacetylene					Metal-Arc					Oxyacetylene		Metal-Arc	
	Gas per hour		Cost for gas per foot run pence	Iron wire for filling, pence	Labor per foot run	Power per foot run			Labor per foot run, pence	Cost of electrodes per foot run, pence	Feet run per hour	Total cost per foot run, pence	Feet run per hour	Total cost per foot run, pence
	Oxygen, cubic feet	Acetylene, cubic feet				Volts	Amp.	Kw.						
1/16	3	2.0	0.116	0.131	0.40	100	30	0.075	0.3	12 in. No. 12 = 1.2	30	0.647	40.0	1.575
1/8	9	6.3	0.77	0.196	0.856	100	75	0.312	0.5	18 in. No. 12 = 1.8	14	1.822	24.0	2 612
3/16	13	9.0	1.72	0.262	1.33	100	100	0.50	0.6	24 in. No. 10 = 2.64	9	3.312	20.0	3.74
1/4	17	13.0	2.70	0.250	1.50	100	140	0.70	0.6	22 in No. 8 = 3.6	8	4.45	20.0	4.90
5/16	27	16.0	4.21	0.327	1.714	100	110	1.10	1.2	12 in. No. 10, 18 in. No. 8 = 4.02	7	6.25	10.0	6.32
3/8	34	24.0	6.82	0.458	2.00	100	120	1.61	1.61	18 in. No. 10, 24 in. No. 8 = 5.58	6	9.278	7.4	8.802
7/16	41	29.0	9.90	0.655	2.40	100	120	2.00	2.0	24 in. No. 10, 36 in. No. 8 = 8.04	5	12.955	6.0	12.04
1/2	48	34.0	14.50	0.786	3.00	100	120	2.40	2.4	30 in No 10, 42 in. No. 8 = 9.6	4	18.286	5.0	14.40

Labor taken at 1 shilling per hour.
Oxygen taken at ½ pence per cu. ft.
Acetylene taken at 1 pence per cu. ft.
Iron for filling taken at 0.131 pence per ft.
The above figures are based on the British Oxygen Co. standards.

Labor taken at 1 shilling per hour.
Current taken at 1 pence per B.O.T. unit.
Electrodes, No. 10, 1.32 pence per ft.; No. 8, 1.8 pence per ft.; No. 12, 1.2 pence per ft.

to be a faster process for all thicknesses of steel. The British Admiralty results furthermore indicate the economic field for the two methods. The verdict from the data in the Table is in favor of gas welding for thin plates and of electric-arc welding for thick plates. But the comparison is based on the very high cost of electrodes set forth below:

Standard wire gauge	Cost in cents per foot	Ft. per pound of contained iron wire	Cost in cents per pound
Number 8	3.6	15	54
Number 10	2.6	23	60
Number 12	2.4	35	84

By substituting a typical American price for labor and substituting the cost of bare electrodes, such as are used with entire success in America, in place of the cost of flux-covered electrodes of the expensive type employed in arriving at the results set forth in the Table, the revised results show a lower cost for arc welding than for gas welding for all thicknesses above $^{1}\backslash_{16}$ inch. The question of the quality of the weld is another matter, but judging from the general reputation of the work of all sorts done by gas welding and by metal-arc welding, they are both thoroughly reliable. No more exact comparison can be made till we have carried through to completion, really elaborate tests of gas welds in order to permit of making a sound comparison with the large amount of research data already obtained with metal-arc welds.

In response to a request for his opinion as to the respective fields for gas and metal-arc welding, Mr. R. E. Wagner, writes as follows: "The present well-tried field for metal-arc welding is confined entirely to welding plates and forms, and a great deal of work has been done on plates varying in thickness from 1/16 in. to ¾ in. Up to 1/8 in. plates, the cost of gas and electric welding is about the same. Beyond this, the cost is in favor of the electric process. No difficulty is experienced in machining electric welds made with the metallic electrode. While it is recognized that the electric-welded-in material will not stand bending equal to that of the plate in which it is deposited, it is on the average equal to gas-deposited material in this respect."

17. Relative Ductility of Arc Welds Made Respectively With Bare and Covered Electrodes

By some authorities, ductility is believed to be most readily obtained by employing flux-covered electrodes. On the other hand, the Committee has knowledge of several kinds of bare electrodes of various compositions which, in competent hands, make reasonably ductile welds.

18. Speed of Arc Welding

All sorts of values are given for the speed, in feet per hour, with which various types of joints can be welded. Operators making equally good welds have widely varying degrees of proficiency as regards speed. Any quantitative statement must consequently be of so guarded a character as to be of relatively small use. In general, and within reasonable limits, the speed of welding will increase considerably when larger currents are employed. It appears reasonable to estimate that this increase in speed will probably be about 25 to 35 per cent, for high values of current. This increase is not directly proportional to the current employed because a greater proportion of time is taken to insert new electrodes and the operator is working under more strenuous conditions. Incidentally, the operator who employs the larger current will not only weld quicker but the weld will have also better strength and ductility.

On this point Mr. Wagner writes as follows: "I would not say that speed in arc welding was proportional to the current used. Up to a certain point ductility and strength improve with increased current, but when these conditions are met, we do not obtain the best speed due to increased heating zone and size of weld puddle. Speed may fall off when current is carried beyond certain points."

In a research made by Mr. William Spraragen for the Welding Research Sub-Committee on several tons of half-inch-thick (12.7 mm.) ship plate, the average rate of welding was only two feet (0.6 m.) per hour. Highly skilled welders were employed but they were required to do the best possible work, and the kinds of joints and the particular matters under comparison were very varied and often novel.

However, in the researches carried on by Mr. Spraragen it was found that about 1.9 pounds (0.8 kg.) of metal were deposited per hour when using a 5/32 in. (3.9 mm.) bare electrode and with the plates in a flat position. The amount of electrodes used up was about 2.7 pounds per hour, of which approximately 16.5 per cent was wasted as short ends and 13 per cent burnt or vaporized, the remainder being deposited at the speed of 1.9 pounds per hour mentioned above.

For a 12-foot-cube tank of half-inch-thick steel welded at Pittsfield, the speed of welding was 3-feet per hour. The weight of the steel in this tank was 16,000 lb. and the weight of electrode used up was 334 lb. of which 299 lb. was deposited in the welds. The total welding time was 165 hours corresponding to using up electrodes at the rate of just 2 lb. per hour. The total length of weld was 501 feet, the weight of electrode used up per foot of weld thus being 0.60 lb. The design of this tank comprised eighteen different types of welded joint. Several different operators worked on this job and the average current per operator was 150 amperes.

For the British 125-foot-long Cross-Channel Barge for which the shell plating was composed of ¼-in. and 5/16-in. thick plates, in Mr. H. Jasper Cox's paper read before the Society of Naval Architects on Nov. 15, 1918, and entitled "The Application of Electric Welding to Ship Construction" it is stated that: "After a few initial difficulties had been overcome, an average speed of welding of seven feet per hour was maintained including overhead work which averaged from three to six feet per hour."

In a report appearing on page 67 of the Minutes and Records of the Welding Research Sub-Committee for June 28, 1918, Mr. O. A. Payne, of the British Admiralty, states: "A good welder could weld on about one pound of metal in one hour with the No. 10 Quasi-Arc electrode, using direct current at 100 volts. An electrode containing about 1½ ounces of metal is used up in about three minutes, but this rate cannot be kept up continuously."

The makers of the Quasi-Arc electrode publish the following data for the speed of arc welding in flat position with butt joints, a 60 degree angle and a free distance of ⅛ inch.

Thickness of Plates	Speed in Feet per Hour
⅛ in.	30
¼ in.	18
½ in.	6
1 in.	1.3

I cannot, however, reconcile the high speed of welding ½-inch plate published in this report as 6 ft. per hour, with the report given above by the British Admiralty that a good welder deposits one pound of metal per hour with Quasi-Arc electrode. If the rate given by the manufacturer is correct, it would mean that about four pounds of metal were deposited per hour. On this basis the rate must have been computed on the time taken to melt a single electrode and not the rate at which a welder could operate continuously, allowing for his endurance and for the time taken to insert fresh electrodes in the electrode holder and the time taken for cleaning the surface of each layer before commencing the next layer.

From his observations the author is of the opinion that a representative rate for a good welder lies about midway between these values given respectively by Mr. Payne and by the makers of the Quasi-Arc electrode, say for half-inch plates some two pounds per hour. This, it will be observed, agrees with Mr. Spraragen's experience in welding up some six tons of half-inch ship plate with a dozen or more varieties of butt joint and Mr. Wagner's results with the eight-ton tank. Even this rate of two pounds per hour is only the actual time of the welding operator after his plates are clamped in position. This preliminary work and the preparation of the edges which is quite an undertaking, and requires other kinds of artisans, accounts for a large amount of time and should not be underestimated.

The practise heretofore customary of stating the speed of welding in feet per hour has led to endless confusion as it depends on type of joint, height of weld and various details. A much better basis is to express the speed of welding in pounds of metal deposited per hour. Data for the pounds of metal deposited per hour are gradually becoming quite definite. The pounds of metal per foot of weld required to be deposited can be readily calculated from the drawings or specifications. With the further available knowledge of the average waste in electrode ends and from other causes, the required amount of electrode material for a given job can be estimated.

19. Suitable Current for Given Cases

For a given type of weld, for example, a double Vee weld in a one-half-inch-thick ship plate, it was found that in the summer of 1918, while some operators employed as low as 100 amperes, others worked with over 150 amperes. Some, in making such a weld, employed electrodes of only ⅛ in. diameter and others preferred electrodes of twice as great cross-section. For the particular size and design of weld above mentioned, the Welding Research Sub-Committee has since had welds made with from 200 to 300 amperes. The conclusion appears justified that the preferable current for such a weld is at least 200 amperes. If the weld of the half-inch-thick plate is of the double-bevel type, some 50 amperes less current should be used for the bottom layer than is used for the second layer, if two layers are used. For three-quarter-inch-thick plates, the most suitable welding current is some 300 amperes. This is of the order of twice the current heretofore usually employed for such a weld.

Mr. Wagner writes: "We have made a number of tests to determine the effect of varying current on the strength of the weld. Tests were made on a ½-in. plate with current values as follows: 80, 125, 150, 180, 220, 275, and 300 amperes. These tests show improvement in the tensile strength and bending qualities of welds as the current increases. The speed of welding increases up to a certain point and then decreases."

20. Effect on Arc Welding of Voltage Employed

Mr. Wagner reports as follows: "We have made a number of tests to determine the influence of variable voltages on the strength and character of electric welds. The experiments were made welding ½ in. plate with 150 amperes held constant and voltage varying as follows: 40, 75, 100, 125, 150, 200 and 225 volts.

"This test demonstrates that there is no material difference in the tensile strength, bending qualities or the appearance of the welded-in material. There is this advantage, however, in the higher voltage, that variations in the strength of the arc do not materially affect the value of the current.

"A curve-drawing ammeter was installed on the welding circuit which showed variations in current at 75 volts, but at 150 volts the current curve was practically a straight line."

21. Preferable Size of Electrode

On certain railways, a single diameter of electrode is employed independently of the size or shape of the plates or parts being welded. The experience of other people leads them to make use of several different sizes of electrodes according to the size of the job and the type of joint. Present British practise appears to be to use such a size of electrode as to have a current density of some 4000 to 6000 amperes per square inch. The investigations of the Welding Research Sub-Committee indicate that at least 10,000 to 12,000 amperes per square inch is suitable for electrodes of 1/8 in. and 5/32 in. diameter and well up toward 10,000 amperes per square inch for electrodes of 3/16 in. and 3/4 in. diameter.

22. Automatic Machinery for Arc Welding

Several firms are developing machinery for feeding the electrode automatically. Such machinery appears to be capable of making excellent welds at higher speeds than are attainable by hand feeding.

23. Carbon-arc Welding

With the advent of metal-arc welding there has been a tendency to neglect the carbon-arc method. It is quite possible that this attitude is not justified for not only is there now a definite field where the carbon-arc method is advantageous but developments in the art may greatly extend its application.

It is generally agreed that the carbon-arc method is not applicable to vertical and overhead welding, which is, of course, a serious handicap in ship-hull work. The majority opinion of competent observers (with, however, some emphatic dissenting views) appears to indicate that carbon-arc welding is not as reliable as metal-arc welding in ordinary welding, because:

a. Carbon is carried into the deposited material thus reducing its ductility.

b. It is more difficult to obtain good fusion on account of overlapping of deposited metal on the original metal.

c. It is more difficult to manipulate and thus requires greater skill.

d. It is a much hotter arc which means greater discomfort to the operator and therefore lower efficiency.

e. Greater cooling stresses are developed because larger areas of adjacent metal are heated.

On the other hand, it is contended by some that carbon-arc welding can be developed to the point where these objections will no longer exist and thus gain the advantages of this method, the principals of which are:

a. No preparation of the abutting edges is necessary.

b. Greater rate of deposition of metal and therefore greater speed of welding, particularly in heavy work.

c. Probable greater adaptability to automatic welding.

It should be stated that there is very general agreement as to the superiority of the carbon arc over the metal arc for heavy work where strength is not so important, especially cast-iron welding and the filling of holes in iron and steel castings.

24. Preparation of Welding Edges

British practise permits the use of smaller angles when the edges of the plates are Veed, than accords with American traditions. If the smaller angles give welds which are equally satisfactory in all respects, the decreased amount of electrode material required, the decreased consumption of electricity,

TABLE III.—TIME, METAL, AND CURRENT USED WITH WELDS OF DIFFERENT BEVELS

	Angle of Bevel Used, in Degrees			
	15	30	45	60
Amperes	160.	145.	118.	125.
Weight of electrode used up (lb.)	2.56	3.83	4.63	6.63
Weight of metal deposited (lb.)	1.70	2.55	3.65	5.08
Weight of metal wasted (lb.)	0.86	1.28	0.98	1.55
Pounds deposited per hour	1.82	1.61	1.82	1.81
Feet welded per hour	3.22	1.90	1.50	1.07
Circuit kilowatts	9.91	9.00	7.68	8.25
Kilowatt-hours per foot of weld	3.10	4.70	5.10	7.70

and the increased speed are advantages not to be overlooked; but obviously the matter requires careful investigation. American practise which, up to recently, has been with a very wide angle, appears to have required the consumption of about twice as great a weight of electrode as British practice with the smaller angle. The urgent importance of determining whether the use of the smaller angle involves any sacrifice in quality is evident. There is already considerable basis for the belief that actually better results attend the employment of a smaller angle of bevel when a suitably large current is used. A shoulder in place of the heretofore commonly used sharp bottom edge of the bevel, also constitutes a material gain not only in the saving in welding material, but also in the quality of the weld.

Mr. Wagner states that at Pittsfield they have long adopted the practise of using a 30-degree bevel for plate edgings and that they find it satisfactory for all thicknesses up to ¾ in. He states that this angle gives sufficient room for depositing the metal, reduces the time to weld and the amount of metal deposited.

In one of Mr. Spraragen's researches, various angles of bevel were used. Although the physical tests have not yet been made we can gain from Table III valuable lessons on the time, amount of metal, and electricity consumed for these different angles of bevel. The "free distance" in each case was ⅛ in. and the welding was done in a flat position with 5/32-in. bare electrodes. In each case the weld had a length of three feet.

25. Quality of Overhead Arc Welding

The British Admiralty regards overhead welding as too inferior and too expensive to be employed when it can possibly be avoided. In America a large amount of overhead welding is done in railway shops and it is claimed that it is simply a matter of training operators to the required degree of proficiency.

26. Number of Layers to be Employed

Good progress is being made in obtaining knowledge of the relative characteristics of welds made with different number of layers and of the most suitable current and the most suitable size and type of electrodes to employ for each layer. The tendency is toward the use of at least two layers for half-inch-thick plates, and three layers for three-quarter-inch-thick plate.

27. Rigid vs. Non-rigid Methods of Welding

On this question it is more a matter of determining the conditions essential to obtaining good results with whichever of the two methods is most appropriate for each particular purpose.

The term *rigid* is applied to the process of arc welding, in which the two parts to be joined by welding are, prior to welding, held rigidly by bolting or clamping or by a series of preliminary tack-welds distributed at various points. The rigid plan is the most obvious for welding the hull plates of ships but its critics claim that the resultant joints are deficient in ductility due to the presence of internal stresses. It is considered that by suitably arranging the order of welding it is practicable to so distribute the heat as to avoid these stresses. At any rate, there are many alternative orders of procedure in making welds by the rigid method and elaborate researches should be made to ascertain the procedure which will yield the best result.

The non-rigid method consists in placing at a slight angle to each other the two plates to be welded. As the welding operation progresses along the seam the angle gradually closes and when the weld is completed the width of the welded seam is equal throughout its extent. Such welds are generally considered to be very free from internal stresses, and hence more ductile.

28. Consequences of Different Lengths of Arc

The metal arc is much shorter than the carbon arc. As a result the metal arc weld has the advantage that there is less opportunity for oxygen and nitrogen to gain access to the weld and so far as relates to this feature the metal arc weld should be better. But with the carbon arc the added metal does not traverse the arc, the tip of the welding rod being held down close to the surface on which it is to be deposited. This may render the deposited material less subject to contamination in carbon arc welding than in metal arc welding since it has not traversed the arc.

Coming to the exclusive consideration of metal-arc welding, the greater the welding current the less is the area represented by the cylindrical surface of the arc per pound of metal traversing the arc, and consequently the less should be the contamination by oxygen and nitrogen from the surrounding air. So far as this circumstance is concerned, the greater the welding current, for a given case, the greater should be the ductility of the joint. On the other hand, it seems probable that even the most skilful operators will be unable to hold quite so short an arc with the larger current.

29. Spot and Arc Welding

A good deal of progress is being made in America in the use of spot welding for the joining of thick plates. It is believed that spot welding has a great future as applied to shipbuilding and several large spot welders have been built for shipyards.

In some of its applications, spot welding affords a method of preliminarily joining the hull plates, after which the required additional strength is provided by arc welding. The Welding Research Sub-Committee has already made some progress in comparing combined spot and arc welds and combined rivet and arc welds with riveted, spot-welded, and arc-welded joints.

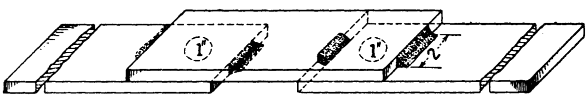


FIG. 9—FILLET AND SPOT WELDED

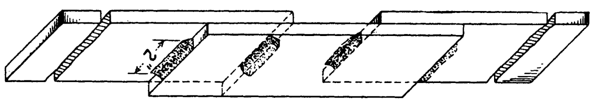


FIG. 10—FILLET WELDED

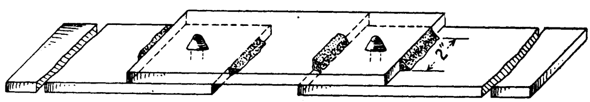


FIG. 11—RIVETED AND FILLET WELDED

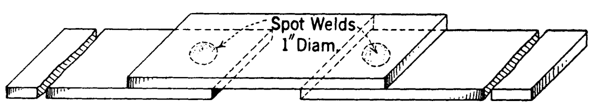


FIG. 12—SPOT WELDED

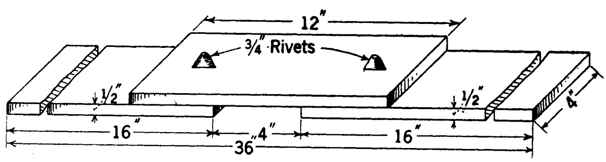


FIG. 13—RIVETED JOINT

It is not a question in such an investigation of spot *versus* arc welding, but of spot *and* arc welding.

In the tests mentioned, the specimens were made up of the following combination:

1. Spot and fillet welded Fig. 9 (2 samples made).
2. Fillet welded—made by welding fillets about two inches in length at the ends of the plates Fig. 10 (2 samples made).
3. Riveted and fillet welded Fig. 11 (1 sample made.)

4. Spot welded—made by welding two spots approximately one inch in diameter, on the plates Fig. 12 (2 samples made).

5. Riveted joint, made by riveting a ½-inch by 4-inch by 12-inch plate with two plates ½-inch by 4-inch by 16-inch, using two ¾-inch rivets and a 4-inch lap. (One sample made).

The results of the test show the comparative strength of the joints as follows:

Spot and fillet welded—ultimate load...			*50,350 lb.
Fillet welded—	"	" ...	*37,000 "
Riveted and fillet welded—	"	" ...	†35,000 "
Spot welded—	"	" ...	*28,000 "
Riveted Joint—	"	" ...	†13,000 "

Spot welds, as compared with arc-welded butt joints, have the disadvantage of the increased weight corresponding to the overlap.

30. Condition of Surfaces to be Welded

While for spot welding the surfaces may sometimes be *too* clean to obtain the best weld, this cannot be the case with fusion welding. The question of the extent to which it is practicable to go in freeing the surfaces from impurities prior to making the fusion weld is entirely a commercial one. The cleaner the surface, the better the weld. In spot welding it is desirable to have clean surfaces under the electrodes, but scale *between* the two plates is a positive advantage.

31. Pre-heating and Heat Treatment and Hammering While Cooling

Pre-heating, heat treatment and hammering, as applied to fusion welding (both gas and electric) have been the subjects of research, but as yet nothing adequately comprehensive has been planned. It is very important that these deficiencies should be recognized and remedied.

32. Time Required to Train Welders

As to the training of welders, there are on the one hand those who are so ill-informed as to assert that good welding can be done after a very few weeks of training, while on the other hand, others assert that an operator can hardly acquire any considerable degree of skill in much less than a year. Still others

*Average of tests on two samples.

†Only one sample made.

advocate the substitution of automatic feeds and the complete elimination of dependence upon manual dexterity. For arc welding work requiring more than 100 amperes this is, in the author's opinion, not a trade for women when the arc is manipulated by hand as distinguished from the use of automatic or semi-automatic machinery.

33. Question of Need for Special Machines for Welding

A great variety of machinery for supplying and controlling the current for welding is on the market. Some of this machinery comprises elaborate mechanisms in virtue of which it is claimed that it would be very difficult for even a novice to make a bad weld. Some advocate the use of simple resistance to be inserted in series with the arc on any available circuit, and claim that any additional machinery is superfluous. The capital outlay for the equipment of a welder (at the point of consumption) when the first kind of equipment is used, may be a matter of over $1000.00, while in the second case, well below half of that sum is sufficient.

34. Technique of Testing Welds

The ideal weld should presumably be at least as strong and as durable as the metal of the members joined together. In other words, the section containing the weld should have the same chemical and physical characteristics as adjacent sections in the original metal. A weld is therefore measured by the degree of approximation to this condition as dertermined by mechanical, chemical and metallurgical tests of:

a. The parent metal
b. The welded joint
c. The deposited material in the weld.

While during the last year the Welding Research Sub-Committee has made a great deal of progress in establishing standard procedures for the mechanical testing of welds, much still remains to be done. Obviously, the procedure for testing the original metal should follow standard practise as recommended by the American Society for Testing Materials, but there is considerable difference of opinion and uncertainty as to just how and what mechanical tests should be made of the welded joint and of the deposited metal. For instance

a. Should all the usual observations be taken when making a tensile test of a welded joint? Obviously the strength of the union between the two pieces of metal should be determined but in view of the non-homogeneity of the specimen, does not a very different significance attach to yield-point, elongation and reduction of area? Where a series of welds having the same ratio of deposited material to original metal is concerned, such data are undoubtedly important for comparison purposes but for evaluating a weld in terms of the original metal, questions are repeatedly being raised as to just what extent these data have value.

b. Would not more reliable information as to the ductility of the weld be obtained if elongation and reduction of area measurements were made on specimens prepared from the deposited metal or from specimens cut lengthwise of the weld instead of crosswise?

c. Similarly with the bending test, which is a test for ductility. There are some (including the author) who would make the bending with the axis of the mandrel *normal* to the weld instead of parallel thereto, which latter position is the one usually employed. It may be that both tests should be made; the normal position as test of the ductility of the deposited material and the parallel position as an additional test of the union between the deposited material and the original metal.

d. How important are torsion tests and impact or shock tests in measuring welded joints?

e. Fatigue tests of welded joints are generally conceded to be vital and the importance of obtaining reliable information as to how this test should be made probably transcends (at present at least) that attached to any other research in the field of fusion welding. The researches should be made:

1. With the Moore bending fatigue machine
2. With rod samples rotated at high speed, as employed by Lloyd's Register in England
3. With the Strohmenger torsion-fatigue machine
4. With the Cammell-Laird bending fatigue apparatus
5. By the Upton-Lewis test.

After the necessary research work has been done to solve these and other similar questions pertaining to the testing of welds, standard specifications for the testing procedure can be prepared which will be properly balanced between the cost of making the tests and the amount of testing necessary to insure a reliable estimate of the weld.

Conclusion

The extent of the field of application for fusion welding and spot welding is but little appreciated by engineers other than those who have been directly connected with welding developments. It is evident that this field is an enormous one, including as it does all structures where steel is employed, such as bridges, building structures, tanks of all types and kinds, railway rolling stock, and ships, in addition to numberless miscellaneous applications in industry in general.

However, engineers associated with welding research should be on their guard that their enthusiasm over this great field of application shall not lead them into prematurely endorsing the use of fusion welding or spot welding in constructions where the consequences of failure involve serious menace to life and property, as may often be the case. For example, a particularly important case is that of pressure vessels and especially large high-pressure containers. The success in one hundred installations will not excuse failure (accompanied possibly by fatalities), in the one hundred and first installation. It is the opinion amongst the best informed engineers that before fusion welding can advisedly be employed for large high-pressure vessels, much vigorous and elaborate research work should be carried out on the fatigue characteristics of fusion welds of long seams, and that this research work must comprise full-sized structures since the conditions cannot be reproduced in test samples.

In fact, if the general acceptance of welding, particularly by Inspection boards, underwriters, and classification societies, is to be accomplished in a reasonably short time, such extensive research work on a large scale is absolutely essential in order to demonstrate conclusively that welded joints are equal to or better than joints made by other methods. Obviously the development of the art could proceed along the lines of the usual order of evolution as in the cases of previous arts, but this would, as in those cases, involve the lapse of years.

For structures subjected to less extreme stresses, such as the hulls of ships, the adequacy of fusion welding as a substitute for riveting is in process of being thoroughly demonstrated in actual practise in Great Britain. It is recognized that the hulls of ocean-going ships are exposed to very great stresses, nevertheless there is a clear distinction between the magnitude of those stresses and the stresses to which many large, high-pressure containers are subjected.

The author hopes this paper will aid in focusing attention on the vast importance of the welding art, particularly by occasioning discussion of the many problems in welding research some of which have been mentioned in the paper.

The author cannot undertake to give adequate acknowledgment of his indebtedness to his many associates in the preparation of this paper. The most generous assistance has been given him on every hand. Mr. William Spraragen has extended much assistance in preparing data and in many useful ways. Mr. F. M. Farmer, chief engineer of the Electrical Testing Laboratories, has given very generously of his time in advising the author in detail about many points which arose in the course of the preparation of this paper.

Four Appendices accompany this paper:

Appendix A: Standard Procedure for Testing Welding Electrodes.

Appendix B: The Wirt-Jones Tests of Arc Welded Half-inch Ship Plates.

Appendix C: Bending Tests of Gas Welds.

Appendix D: Arc-Welded Steel Box.

Appendix A

STANDARD PROCEDURE FOR TESTING WELDING ELECTRODES.
WELDING COMMITTEE, EMERGENCY FLEET CORPORATION
NOVEMBER, 1918

1. *Purposes.* The purpose of this specification is to provide a standard procedure for testing welding electrodes for metal-arc welding which are submitted for the information of, and with the view to the approval by, the Welding Committee of the Emergency Fleet Corporation.

Note.—This specification describes a test *of electrodes* and not a combination of an electrode and of an apparatus. The fact that the applicant is given the option of selecting the system with which the test is made, does not make it a test of that system, any more than the employment of a particular welding operator could be said to make it a test of a welding operator. The system used in making these tests may or may not prove to be of importance. It is sought to minimize the influence of the individuality of the operator by requiring the test to include welds made by at least two operators.

The Welding Committee has two other Sub-Committees into whose province falls the approving and certifying of operators and approving and certifying of systems. The admission that these three tasks overlap does not involve any reason for delaying the important task of proceeding at once with the standardizing of the testing *of electrodes.*

2. *General Conditions.* a. Each applicant shall provide at his factory or elsewhere as he may elect, the necessary facilities and at least two operators for making the test welds prescribed by these specifications. Except when otherwise indicated in these specifications, the applicant shall select the apparatus and other conditions for making test welds which he considers most suitable for his electrodes.

b. The test welds shall be made in the presence of an *authorized representative* of the Welding Committee of the Emergency Fleet Corporation who will be empowered to certify as to the compliance with the conditions prescribed in the specifications. Also representatives of Lloyd's Register of Shipping and the American Bureau of Shipping shall have the opportunity to witness the making of the test welds.

c. Until otherwise declared, the *authorized representative* of the Welding Committee shall be the Electrical Testing Laboratories, 80th Street and East End Avenue, New York, N. Y.

d. The Welding Committee shall assume charge of the completed test welds and have them tested by the *authorized representative* in accordance with these specifications.

e. The *authorized representative* shall render to the Welding Committee a complete, detailed report of each test of an electrode.

f. The cost of carrying out the prescribed tests shall be borne by the applicant.

3. *Sample Electrodes.* About 100 pounds of each electrode to be tested, which will be known as the *sample,* shall be furnished without charge. It shall be accompanied by an affidavit giving the following information:

a. The *trade name* under which the electrode is marketed together with certification that all electrodes bearing this trade name will be substantially the same as the sample submitted.

b. The manufacturer of the complete electrode.

c. The location of the factory in which the electrode was made.

d. The manufacturer of the welding wire.

e. The location of the mill in which the welding wire was produced.

f. The chemical analysis of the welding wire.

The *authorized representative* shall retain the remainder of the sample for reference purposes.

4. *Plate Material.* For these tests one-half inch ship plate shall be used. This material shall comply with the "*standard specification for structural steel for ships*" as adopted by the American Society for Testing Materials, serial designation A 12–16 (see page 98, A. S. T. M. Standards, 1918).

An abstract of this specification is as follows:

1. Open hearth steel.

2. Phosphorous $\begin{cases} \text{acid steel, not over 0.06 per cent.} \\ \text{basic steel, not over 0.04 per cent.} \end{cases}$

Sulphur, not over 0.05 per cent.

5. Tensile strength, pounds per square inch, 58000–68000

Yield point, minimum pounds per square inch, 0.5 tensile strength.

Elongation in 8 inches, minimum per cent., $\dfrac{1{,}500{,}000}{\text{tensile strength}}$

6. Yield point by drop of beam method.

7. Cold bend test; no cracking on outside of bent portion when bent 180 degrees around a pin the diameter of which is equal to the thickness of the plate.

5. *Cutting of Plates.* a. The method of cutting a plate 5 feet by 20 feet into pieces for welding is shown in the accompanying reproduction of drawing No. 102 of the Bureau of Standards.

b. Each plate shall be given a distinguishing letter, A. B. etc. This letter shall appear upon each piece cut from it.

c. Pieces shall be plainly marked with the letter and number arranged as shown in the drawing so that the location of the piece in the plate may be determined.

d. The plates from which tensile, cold bend and fatigue specimens are to be made, shall be cut into pieces 9 inches by 30 inches (see Fig. 14.)

e. The plates from which impact specimens are to be made shall be cut into pieces 30 inches by 30 inches (see Fig. 17).

Notes.—A power shear may be employed for cutting these plates if they are left flat. Pieces whose dimensions are within ¼ inch of the required size will be satisfactory.

6. *Arrangement of Piece for Welding.* a. All welds are to be made across the grain, that is, the welded joint is to be at right angles to the direction of rolling. Fig. 15 shows the correct arrangement of the pieces for the test welds to be used

FIG. 14

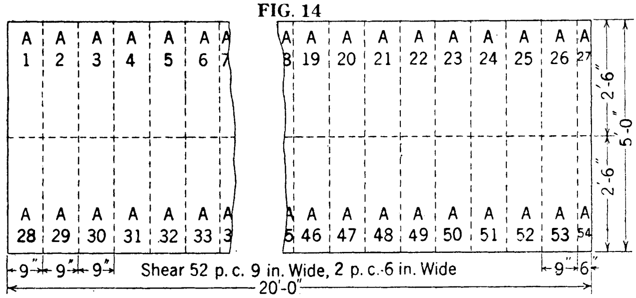


FIG. 15

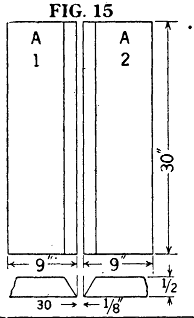


FIG. 16

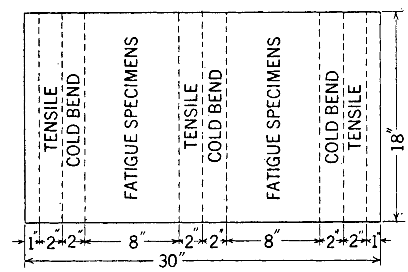
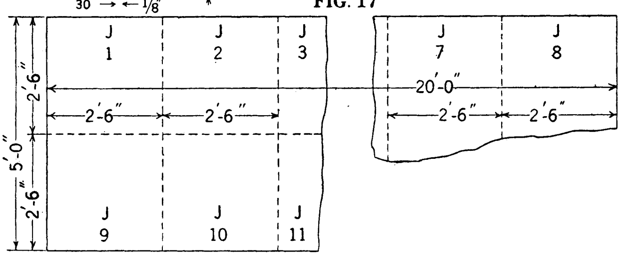


FIG. 17



Specimens for Tests of Welding Electrodes. Welding Research Sub-committee Emergency Fleet Corp. Bureau of Standards, Wash., D. C.

No. 102—VII-I Nov. 9, 1918

Changed Nov. 25, 1918

for the physical tests, but in Fig. 17, which shows the arrangement of pieces for the impact test, pieces such as J–1 and J–2 should be taken for a test weld instead of J–1 and J–9.

b. Preparatory to making a weld, one 30-inch edge of each piece will be beveled at the angle preferred by the applicant.

If he has no preference, the angle of the bevel shall be 30 degrees as shown in Fig. 15. The bevel is not to be carried through to the bottom edge but only to within 1/16 inch of the bottom edge. In other words, the ends of the pieces to be welded are not to be beveled to a sharp point but 1/16 inch of the original square edge will be left at the bottom of the Vee.

c. For welding, the pieces shall be placed horizontally with their under surfaces raised approximately 1/8 inch above the supporting surface. The beveled edges shall be placed parallel and separated 1/8 inch.

d. The weld shall in all cases be of the type known as a double bevel.

7. *Welding of Pieces.* a. The pieces, which shall be dry and free from rust and foreign substance, shall be "tacked" at each end and in the middle of the joint by welding the plates at each of these places for about one-half inch.

b. After "tacking" the weld shall be completed by working continuously from one end of the joint to the other. The welding material shall be added in at least two layers and when completed the surface of the weld shall be at least flush with and not more than 1/8 inch above the upper surface of the plate. The width of the weld at the top shall not be greater than 1 1/4 inches. All welding shall be done from the open side of the Vee.

c. After each layer of a weld is completed, it shall be inspected by the *authorized representative.* If unsatisfactory, a new test weld shall be substituted and a report made of reasons for rejection.

8. *Number of Test Welds.* a. The welds will be made by three skilled operators, two of whom will be furnished by the applicant and one by the Welding Committee.

b. Each operator shall make one 30-inch weld for the tensile, cold bend and fatigue tests (see Figure 15) using direct current and a similar weld using alternating current. For these tests, therefore, six (6) test welds will be required for each sample electrode.

c. Each operator shall also make one 30-inch test weld for the impact test (see Fig. 17) using direct current and a similar weld using alternating current. For impact tests, therefore, six (6) test welds will be required for each sample electrode.

d. If, however, the applicant intends his electrode for use with only one kind of current, that kind only shall be used in making the welds. In that case only three (3) test welds will be reauired for (b) and for (c) instead of six (6).

9. *Arrangement of Conductors.* a. One of the conductors shall be attached to a clamp which will be fastened to both pieces at the end of the joint opposite that from which work is started.

b. For direct current work, the electrode shall have the polarity desired by the applicant. In the absence of any preference on his part, the instructions of the *authorized representative* shall be followed.

10. *Welding Data.* The following information and observations shall be reported by the *authorized representative* during the welding operations.

a. Trade name or other identification mark of the electrodes.

b. Complete description of the electrode.

c. Sufficient description to identify the welding apparatus or system employed.

d. Identification marks on the pieces being welded.

e. Name of operator.

f Kind of current (*i. e.*, direct current or alternating current); if direct current, polarity and if alternating current, frequency.

g. Electrical quantities as follows: arc volts (both open and closed circuit), arc current and arc watts.

h. Room temperature and humidity.

i. The opinion of the *authorized representative* of the working quality of the electrode. This statement to include a description of any sputtering, boiling or other noticeable peculiarities.

j Elapsed time per weld.

k. Weight of electrode consumed per weld.

l. Any other information which will assist in determining the performance of the electrode, such as a photograph of at least one weld, etc.

11. *Preparation of Welded Plate and of Specimens for Physical Tests* (see Fig. 16).

a. Each test weld shall be machined down on both sides to about the surface of the plate.

b. Specimens shall be cut from *each* test weld reserved for physical tests as follows:

1. *Three Tensile Specimens.* These shall be machined to a uniform width of 1.5 inches unless a weld of great

strength makes it necessary to leave shoulders at the ends, in which case the standard A. S. T. M. test specimens for sheet iron and steel shall be prepared.

2. *Three Cold Bend Specimens.* These shall be machined to a uniform width of 1.5 inches.

3. *Six Fatigue Specimens.*—These shall be machined to about ½ inch diameter and 10 inches long. (The exact dimensions are to be determined by experiment.)

12. *Physical Tests.* a. *Tensile Strength.* Each of the three specimens shall be tested in accordance with the practise recommended by the A. S. T. M. and shall include the determination of the tensile strength, yield point (by drop-of-beam), method), reduction of area and total elongation after rupture in two inches and in eight inches.

b. *Cold-bend Test.* This test shall be made by placing the specimen on two rollers with the apex of the Vee upward and midway between the rollers and loaded at the center of the span thus formed by a cylindrical surface having a diameter of one-half inch. This surface shall bend the specimen downward between the rollers until a fracture appears on the lower side of the specimen when loading shall be stopped and the angle noted through which the specimen has been bent.

c. *Fatigue Test.* Each of the six specimens shall be tested in a special rotating type of machine similar to that used by Lloyd's Register of shipping. (Exact details to be determined by experiment.)

d. *Impact Test.* Each impact-test specimen shall be placed on supports 18 inches high and 4½ feet apart. A spherical weight of 500 pounds shall be allowed to fall freely through a distance of 10 feet striking the weld which shall be at the center of the span. The apex of the Vee shall be upward.

e. *Test of Original Plate.* In order to establish the physical properties of the unwelded plate, tensile, cold-bend and fatigue tests shall be made on a sample selected at random from the pieces used for the test welds but before such welds are made.

OPTIONAL TESTS

The following tests are optional with the applicant but the welding Committee considers that they give information of great importance and recommends that they be made in order to make the report on the electrode more complete.

13. *Chemical Analysis.* A chemical analysis shall be made of:

a. The original plate in one test weld selected at random.

b. The metal at the center of one test weld selected at random. If test welds are made with both direct current and alternating current, an analysis shall be made of one weld of each set.

14. *Photomicrographs.* Photomicrographs shall be made of one specimen weld selected at random as follows: (If test welds are made with both direct current and alternating current, photomicrographs shall be made of one weld of each set.)

a. At center of weld.

b. At juncture of weld and original metal.

c. In adjacent original metal.

d. Cross section of electrode.

e. Longitudinal section of electrode.

Appendix B

WIRT-JONES TESTS OF ARC-WELDED HALF-INCH SHIP PLATE

In Tables IV and V are set forth the results of the tests carried out in 1918 on arc-welded half-inch ship plate by the Welding Research Sub-Committee. The plates with which the welds were made had their edges prepared with a 45-degree double-Vee. The welds were made by a dozen different concerns. In each instance the operator employed whatever conditions were considered most suitable. Several types and sizes of electrodes, including both bare and covered, were used. While in the majority of cases direct current was employed, alternating currents of 25 and 60 cycles are also represented in the series. The number of layers and the current employed and, indeed, all the conditions, were left to the discretion of the individual operator. The length of the weld was eight inches. After the welds were made, the plates were cut up and tests were made at the Bureau of Standards under the direction of Prof. H. L. Whittemore. The tensile tests were made on specimens with a cross-section of one in. by one-half in. Specimens with the weld machined have the projecting metal planed off so that the welded portion is smooth and of approximately the same cross-section as the remainder of the specimen. For the specimens with the weld not machined, no record was made of the added cross-section due to the projecting material.

The cold bend specimens were one in. by one-half in. and were bent around a mandrel of 1.5 in. diameter. The results

TABLE IV
WIRT-JONES TESTS OF ONE-HALF-INCH ARC-WELDED SHIP PLATES
(Machined Samples)

Test number	Current in amperes a-c.	Current in amperes d-c.	Diam. of elec. in in.	Current density, amp. per sq. in.	Tensile tests: Ult. lb. per sq. in.	Tensile tests: Per Cent. Elon. in 2 in.	Bending: Angle at which crack starts, degrees	Electrode: Cov.	Electrode: Bare	Electrode: Make
20	175	...	0.125	14,227	62,700	9.0	34	C	..	E.A.C.& W.Co.
1	...	175	0.166	9,118	59,800	9.0	42	..	B	Roebling
22	160	...	0.125	13,008	50,000	6.0	78	C	..	E.A.C.& W.Co.
2	...	155	0.156	8,075	62,600	11.5	44	..	B	Roebling
19	150	...	0.125	12,195	62,800	12.0	32	C	..	Quasi
31	...	150	0.166	6,930	60,900	8.0	..	..	B	Roebling
29	...	150	0 156	7,815	56,400	6.5	..	..	B	W.W.& M.Co.
38	150	...	0.156	7,815	54,500	7.0	45	C	..	E.A.C.& W.Co.
29	...	150	0.156	7,815	54,400	6.0	47	..	B	W.W.& M.Co.
9	...	150	0.156	7,815	44,200	4.0	26	..	B	Toncan
9A	150	...	0.187	5,430	42,500	4.0	30	..	B	Armco
10	...	150	0.156	7,815	41,900	4.5	25	..	B	Toncan
10	...	150	0.156	7,815	41,300	4.5	24	..	B	Toncan
9	...	150	0.156	7,815	38,100	4.0	15	..	B	Toncan
9A	150	...	0.187	5,430	36,300	4.0	..	..	B	Armco
5	...	145	0.156	7,554	61,100	8.5	55	..	B	Am.S.& W.Co.
25	136	...	0.156	7,085	43,700	3.5	26	..	B	Roebling
30	...	135	0.156	7,033	53,200	11.0	..	..	B	W.W.& M.Co.
30	...	135	0.156	7,033	52,000	10.5	50		B	W.W.& M.Co.
37	125	...	0.125	10,162	56,400	7.0	42	C	..	E.A.C.& W.Co.
7	...	120	0.125	9,756	57,600	8.5	50	..	B	Roebling
7	...	120	0.125	9,756	53,700	7.0	45	..	B	Roebling
8	...	115	0.125	9,349	59,400	13.5	60	..	B	Roebling
8	...	115	0.125	9,349	58,200	14.0	..	..	B	Roebling
3	...	115	0.156	5,891	50,600	5.0	34	..	B	Am.S.& W.Co.
16	...	110	0.134	7,799	50,250	7.0	35	C	..	Quasi
27	...	110	0.125	8,943	45,800	8.0	42	..	B	Roebling
21	105	...	0.134	7,444	42,200	5.0	42	C	..	E.A.C.& W.Co.
26	94	...	0.125	7,642	34,200	3.0	15	..	B	Roebling
18	90	...	0.134	6,381	54,000	6.0	65	C	..	Quasi
15	...	90	0.134	6,381	39,400	4.0	30	C	..	Quasi
24		86	0.125	7,154	45,400	6.0	15	..	B	Roebling
23	...	85	0.125	6,930	51,900	4.0	..	..	B	Roebling

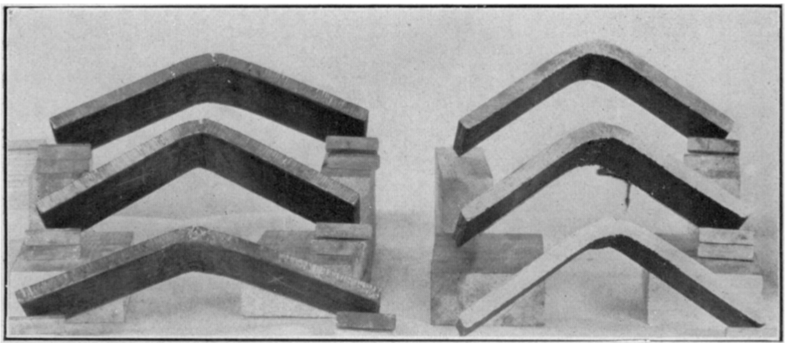


FIG. 8—GAS AND ELECTRIC BENT SAMPLES (GAS WELDS AT LEFT AND ELECTRIC WELDS AT RIGHT)

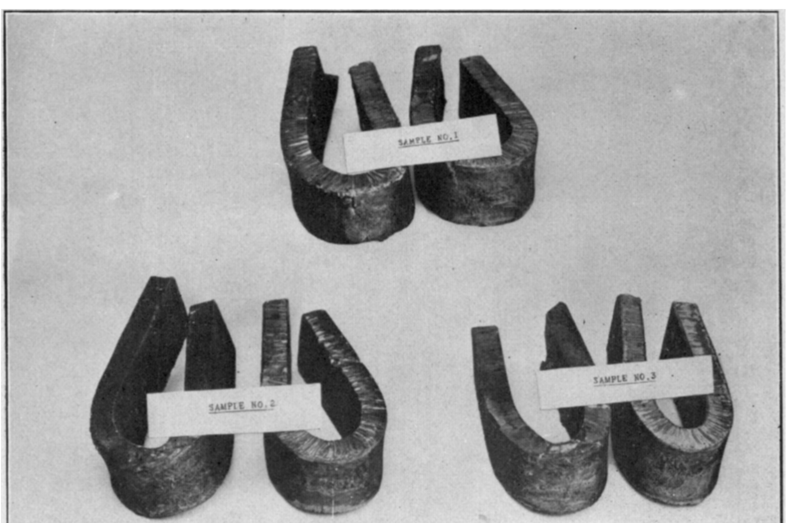


FIG. 18

PLATE XXX.
A. I. E. E.
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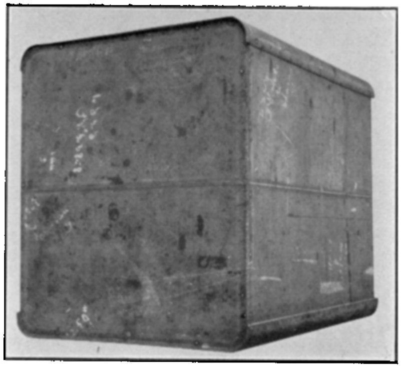
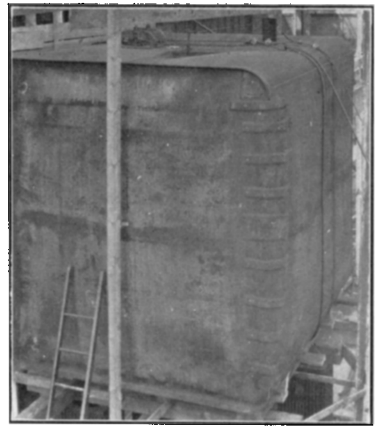
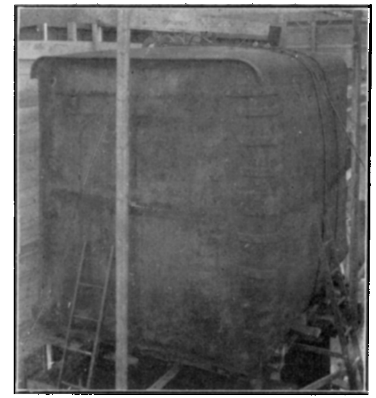


FIG. 20—ELECTRIC-ARC WELDED STEEL BOX OF ONE-HALF INCH TANK STEEL



FIG, 21—ELECTRIC-ARC WELDED BOX UNDER 22-INCH VACUUM—SHOWING TOP SIDE DEPRESSED



[HOBART]

FIG. 22—ELECTRIC-ARC WELDED STEEL BOX UNDER 15 LB. HYDRO-STATIC PRESSURE—ONE PHASE OF THE BREATHING TEST

of the tensile and bending tests for the machined samples are given in Table IV. Those for the samples which were not machined are given in Table V.

TABLE V.—WIRT JONES TESTS OF ONE-HALF INCH ARC-WELDED SHIP PLATES

(Samples Not Machined)

Test No.	Current in amperes		Diam. of elec. in inches	Current density, amp. per sq. in.	Tensile tests		Electrode		
	A. C.	D. C.			Ult. lb. per sq. in.	Per cent elon. in 2 in.	Cov.	Bare	Make of Electrode
20	175	...	0.125	14,275	66,480	11.0	C	..	E.A.C.&W.Co.
22	160	...	0.125	13,008	66,400	9.0	C	..	E.A.C.&W.Co.
19	150	...	0.125	12,195	65,400	6.0	C	..	Quasi
5	...	145	0.156	7,554	52,280	7.0	..	B	Am.S.&W.Co.
25	136	...	0.156	7,085	47,800	4.0	..	B	Roebling
3	...	115	0.156	5,891	65,470	13.0	..	B	Roebling
27	...	110	0.125	8,943	48,200	7.0	..	B	Am.S.&W.Co.
16	...	90	0.134	6,381	58,740	5.2	C	..	Quasi
18	90	...	0.134	6,381	61,760	11.0	C	..	Quasi
15	..	90	0.134	6,381	57,340	8.0	C	..	Quasi
23	...	85	0.125	6,910	57,060	5.0	..	B	Roebling

Appendix C

Bending Tests of Gas Welds

Too late for inclusion in the body of this paper there has been brought to the author's attention some gas welds made under the direction of Mr. H. I. Walsh, which have withstood very severe bending tests before failing. The specimens are shown in the illustration Fig. 18. Three pairs of specimens welded with three kinds of electrodes are shown. These specimens show much greater ductility than those shown in Fig. 8.

Appendix D

Arc-welded Steel Box

Mr. R. E. Wagner has prepared the following description of a large steel box, arc welded with bare electrodes at Pittsfield. The box was built and tested in the latter half of 1918. It was made of half-inch-thick tank steel and its dimensions were 12 ft. by 10 ft. by 9 ft. The total weight was 16,000 lb. The welding was done with 75-volt direct current. This box contained eleven different varieties of welds. Its general dimensions and the types of welds used are shown in Fig. 19. No rivets were used in its construction.

The principal objects to be ascertained in the construction of this box were:

1. Could a structure of this character be made close to drawing dimensions and without excessive distortions and warping of plates and parts?

2. Would the structure be strong and capable of withstanding severe shocks and distortions without serious ruptures?

3. What are the detail costs and time required to build such a structure?

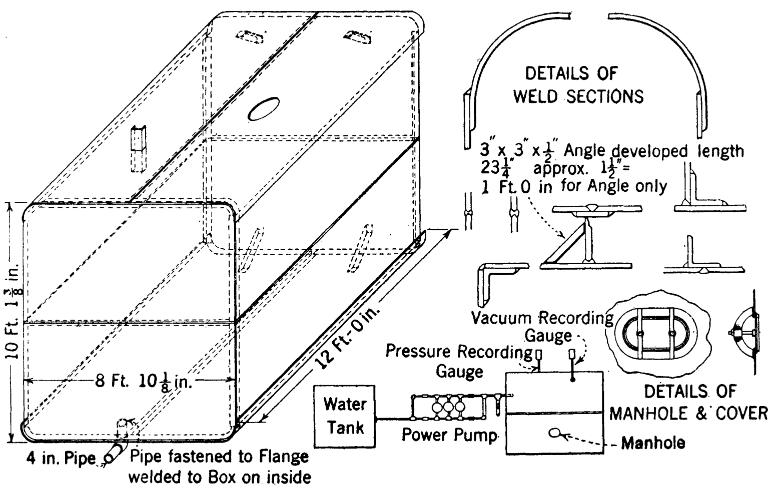


FIG. 19—OUTLINE AND DIMENSIONS OF ARC-WELDED STEEL BOX

It was found that if proper allowances are made for contraction and expansion, especially where plates are butted and welded, the resulting plate will show very little warping. The maximum variation of the sides from a plane was 1.5 in. The general appearance of the box when completed is shown in Fig. 20.

The box, when finished, was strong and well built. All joints had a smooth workmanlike finish. A number of incipient leaks developed when the box was first filled with water, but these were closed by hammering. The box was subjected to a hydrostatic pressure test of 43 lb. per square inch, and, after it had been severely stressed and distorted, it ruptured at a corner, the break starting at the top and opening the entire corner. This corner was afterward repaired (as shown in Fig. 21), and the box was subjected to a "breathing" test consisting of alternate applications of 15 lb. pressure and 22 in. of vacuum.

During each cycle of this "breathing" test, the top of the tank had a maximum movement of 8 in. from bulge to depression. At the sides the movement was 6 in. Every time that the side, bottom and top plates moved from bulge to depression, there was a sharp snap of the plates as they moved from "arch in" to "arch out." These sudden changes in form subjected the welded joints not only to bending stresses but to severe snapping stresses. At the end of the twelfth cycle a break occurred in a double-bevel weld. At one end the break left the weld and went into the solid plate. This break was patched and the "breathing" tests were resumed. The next break which occurred after the 235th cycle of operation extended 24 in. into the solid end plate as well as 17 in. along a weld. This break will be repaired and the tests will be resumed.

The following cost data is of interest:

Welding	$ 151.00
Fabricating and assembling	134.00
Blacksmithing	24.00
Testing and supervision	50.00
Welding wire	30.00
Steel plate	651.00
Total cost	$1040.00

Total pounds of wire used	334
Total pounds of wire deposited and lost	299
Total scrap ends of wire	35
Total feet of welding	501
Total hours of welding	165
Total kilowatt hours	1011
Per cent scrap ends of wire	11
Wire deposited per foot (pounds)	0.6
Kilowatt hours per pound of wire deposited	3.4
Average feet welded per hour	3.0
Average kilowatt hours per foot of welding	2.0
Per cent. of time welder is welding	60
Diameter of welding wire, inch	$^3/_{16}$

Six different welders obtained the results noted, which are representative for a job of this character.